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Marine Boundary Layer Intermittency

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Submitted Jan. 27, 1994 to D. Trizna, ONR
N00014-92-J-1688

Project Abstract

Goals, long-term

To simulate and analyze the turbulent structures which cause intermittency in the marine boundary layer.

To improve the boundary conditions, surface-layer resolution, and subgrid-scale models used in large-eddy simulation (LES), in order to achieve more realistic results at the air-sea interface.

Objectives, near-term

1. Using the large-eddy simulation (LES) code to study the characteristic large structures or "large eddies" that develop in the marine boundary layer.

2. Improving the LES code in three ways. First, we are studying a better treatment of the lower boundary condition that allows for the naturally occurring random fluctuations in exchange coefficients that become more intense as the grid size is reduced. Second, we are modifying the code to gradually increase the grid resolution near the surface. That will increase the fidelity of the solutions by decreasing the reliance on the subgrid-scale model there. Third, we are studying subgrid-scale physics in order to develop better subgrid-scale models for the surface layer.

3. Analyzing surface-layer data with wavelet transform techniques, focusing on the intermittency of heat fluxes over the sea.

Approach

We are analyzing LES databases using objective techniques (empirical orthogonal functions, EOF's) to find the characteristic large scale structures. These large structures play an important role in forcing MBL intermittency.

We are generating LES data on the Cray computer at Penn State but also have imported data from several of Moeng's LES runs at NCAR. We have also obtained direct numerical simulation (DNS) data and field data from several surface-layer experiments carried out by NCAR and others in order to help in the studies of subgrid-scale physics.

We will generate more reluiable surface-layer data by improving the resolution of LES near the air-sea interface. Our technique places more horizontal modes near the sea surface (the surface layer) than in the mixed layer, with a gradual transition between the layers.

Novel subgrid-scale models are being explored, particularly maximum-entropy and autoregressive predictive techniques.

Tasks Completed

We created a version of Chin-Hoh Moeng's NCAR LES code that is more memory efficient, hence allowing us to run larger simulations. We simulated nearly neutral marine boundary layers having a horizontal domain size of 15 km on a side, and an inversion height of 500 m. The runs used about 400 hours of Cray supercomputer time.

The LES code was also run on a smaller, 3 km horizontal domain, with 192^3 grid points. With 15 m resolution in the horizontal, and 5 m in the vertical, these simulations have higher resolution than any previous atmospheric LES.

EOF analysis was applied to LES fields which had been Fourier transformed in the horizontal coordinates. The method provides information on the vertical structure of the turbulence as a function of horizontal length scale.

With J. Wilczak of NOAA/WPL we completed an analysis of the dynamical response of the Nishiyama-Bedard pressure probe.

Scientific Results

Our 15 km LES runs show convective roll structures with a horizontal wavelength approximately four times the inversion height. There is also some evidence for the transmittal of gravity waves through the capping inversion and into the boundary layer.

The LES runs also suggest that the dominant horizontal wavelength of the convective roll structures gradually (i.e., over many large-eddy turnover times) decreases. This suggests that it may not be feasible to achieve statistical stationarity of the large-scale structures in LES. The same is probably also observed in the atmosphere.

We have analyzed archived LES and DNS data and find that the details of the subgrid-scale (SGS) model are important only near the surface. Unfortunately, in that region many of the assumptions traditionally made in SGS modeling (e.g., homogeneity, isotropy) are invalid. We believe that improved SGS models should be tailored specifically for surface-layer turbulence, which is quite different in some ways from that in the mixed layer above. One important feature is the different spatial scales of the horizontal and vertical velocity components.

Maximum-entropy subgrid models has been found to give results that correlate more closely with actual subgrid-scale stresses than do Smagorinsky-type models. The feasibility of implementing these techniques in LES is being explored.

It is known that the mean profiles of wind and temperature found from LES are in error near the surface. Mason and Thomson (JFM, 1993) found that adding a fluctuating component to the SGS model can greatly improve these profiles, but the reasons for this were not clear. We have found that the improvement can be understood through the equation for the streamise component of resolvable-scale turbulent kinetic energy. One term in that equation involves the interaction of the fluctuating stress divergence with streamwise velocity; if this mechanism is not present (as with most SGS models), the mean wind shear is adversely affected. We are studying ways of incorporating this mechanism into SGS models.

We have computed one-dimensional bispectra of the LES velocity fields for both the streamwise and cross-stream directions. They show that the bicoherency is much higher in the cross-stream direction. The meaning of this result is currently being studied.

In an attempt to improve the traditional drag-law formulation in LES, we have derived a conservation equation for the subgrid-scale temperature flux near the surface. This is the flux carried by unresolvable eddies and averaged over the grid area. Close to

the surface it differs negligibly from the surface flux, which is needed for the resolvable-scale equations at the first grid point. We believe this flux conservation equation (and its extensions to momentum and mass) contains the physics of the surface exchange coefficients and, hence, is a suitable foundation for a "dynamic drag law". Since it is based on the resolvable-subgrid decomposition rather than the mean-fluctuating one, it is the LES analog to the Reynolds flux equation.

One difficulty in working with the equation is evaluating its terms, which represent the various maintenance mechanisms for the flux. We traditionally use experimental data for this purpose, but here we need data averaged over a horizontal grid square. Using field and simulation data, we have found encouraging evidence that averaging of time series can be an adequate surrogate for this horizontal area averaging. This opens the possibility that conventional, in-situ turbulence measurements in the marine surface layer can be used to develop a dynamic drag model for LES.

Preliminary results of our study of the intermittency of heat fluxes in the marine surface layer off Scripps pier with wavelet-transform techniques indicate that

a) Over 75% of the heat flux is contained in several highly concentrated regions in wavelet space corresponding to structures of 10 to 300 m scale. This is only weakly sensitive to the wavelet basis. The concentration of momentum fluxes is less extreme and agrees well with the Mahrt-Howell findings (JFM, 1994).

b) The wavelet coefficients are comparably non-Gaussian in the Scripps pier data and in the LAMEX data over land.

Fluctuating pressure is known to have an important role in the unstable surface layer and in air-sea interaction, but pressure statistics have rarely been measured directly. Our finding that the Nishiyama-Bedard probe can function reliably in the surface layer (Wyngaard, Siegel, and Wilczak, *Boundary-Layer Meteorology*, in press) should stimulate its increased use. We understand that Wilczak plans to use the probe in air-sea interaction experiments planned under the MBL ARI.

Accomplishments

Simulation and identification (by EOF analysis) of convective rolls in the atmospheric boundary layer.

Certification that the Nihiyama-Bedard probe can produce reliable turbulent pressure statistics in the surface layer.

PUBLICATIONS FROM ONR-SPONSORED WORK—FY92/FY93

John C. Wyngaard, PI

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C: Kosovic, B., Wyngaard, J. C., and Peltier, L. J., Effects of fluctuating subgrid-scale stresses on mean velocity profiles in large-eddy simulations of boundary-layer flows, International Workshop on Large-eddy Simulations of Turbulent Flows in Engineering and the Environment, Sept. 26–28, 1993, Montreal.

C: Peltier, L. J., Khanna, S., Wyngaard, J. C., and Brasseur, J. G., Interfacing large-eddy simulation with observation: organization of structure-function parameters from LES data, International Workshop on Large-eddy Simulations of Turbulent Flows in Engineering and the Environment, Sept. 26–28, 1993, Montreal.

C: Peltier, L. J. and Wyngaard, J. C., "Local" Structure-function parameters from LES data, *Bull. Am. Phys. Soc.*, **38** (1993), 2189.